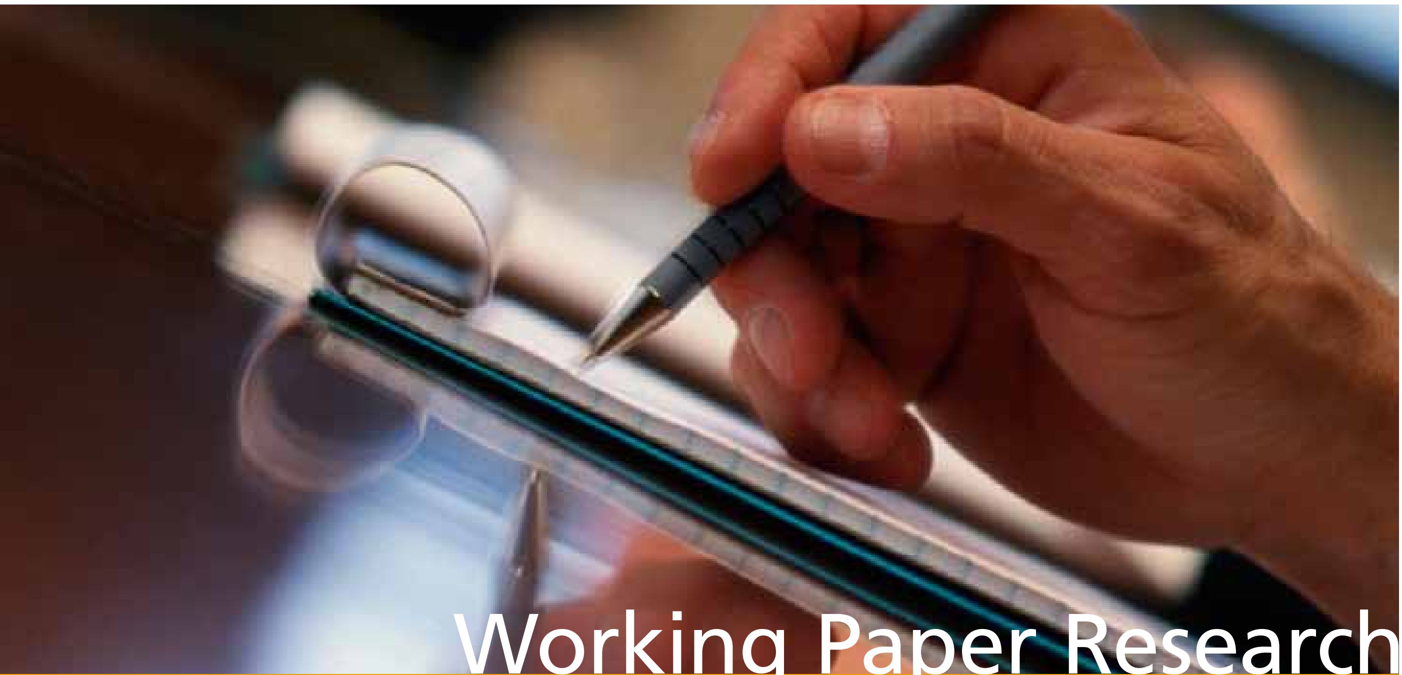
Input-output connections between sectors and optimal monetary policy



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Abstract

This paper considers the monetary policy implications of a model that features input-output connections between stages of production, so that a distinction between CPI inflation and PPI inflation arises. More specifically, this paper addresses the policy conclusion by K. Huang and Z. Liu [2005, "Inflation targeting: What inflation rate to target", *Journal of Monetary Economics 52*], which states that central banks should use an optimal inflation index that gives substantial weight to stabilising both CPI and PPI. This paper argues that these authors' findings rely on the assumption that producer prices are as sticky as consumer prices and it also shows that, once empirically relevant frequencies of price adjustment are used to calibrate the model, CPI inflation receives substantial weight in the optimal inflation index. Moreover, this rule is remarkably robust to uncertainty regarding the model parameters, whereas the policy rule proposed by Huang and Liu can result in heavy welfare losses.

Key Words: Inflation targeting, Optimal Monetary Policy.

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Corresponding author:

Engin Kara, NBB Research Department.
e-mail: engin.kara@nbb.be - mail@enginkara.eu

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TABLE OF CONTENTS

1 Introduction

Over the last decade, many central banks have adopted inflation targeting as a framework for monetary policymaking. Most, if not all, inflation targeting central banks use a measure of consumer price inflation or one of its variants as a target. The use of consumer price inflation seems to be the most relevant measure of inflation if one views the ultimate goal of the monetary policy to be the welfare of households, as this measure is the most relevant for calculating the cost of living[1].

This practice raises a question: should the central banks ignore developments in other measures of inflation, such as the producer price index (PPI)? If the target is CPI inflation, this may seem a pointless question. However, it is important for at least one reason. Increases in the prices of intermediate or crude goods may pass through to consumers, resulting in a higher rate of consumer inflation. The greater is the pass through, the more PPI shocks feed into consumer prices in the economy and cause disruption. Therefore, under an inflation targeting regime, the central banks can minimize the disruptive effect of the PPI on consumer prices by also reacting to PPI inflation.

Another question arises: do increased prices of intermediate or crude goods imply a significant increase in inflation risk at the consumer level in reality? According to Ben Bernanke (2004), the answer is "almost certainly not". Ben Bernanke argues that the main reason behind this is that "raw materials costs are a small portion of total cost". A similar view has been expressed by Jean-Claude Trichet (2004).

If we take the Bernanke view and construct an "optimal inflation index" that is an appropriately weighted average of CPI and PPI inflation rates, CPI should then receive substantial weight and the weight on PPI inflation would be small.

Recent work by Huang and Liu (2005) calls this view into question. Using a Dynamic Stochastic General Equilibrium (DSGE) model that features input-output connections between the stages of production, they argue that a simple inflation targeting rule under which the short-term interest rate responds to an "optimal inflation index" results in a welfare level close to the optimum only in cases where the "optimal inflation index" places substantial weight on both CPI inflation and PPI inflation. More specifically, they find

[1] This view is consistent with the view taken by Woodford (2003). Woodford (2003) stressed that the maximization of the welfare of a representative household should be the appropriate policy objective in DSGE models.

that with their calibrated parameters, the target weight of PPI should be as high as 46% in such an index. Obviously, this finding stands in sharp contrast to the view taken by Bernanke and Trichet.

However, unfortunately, in arriving at their conclusion, Huang and Liu ignore the possibility that sectors may have different characteristics and make a strong assumption that the sectors are identical in all respects. For example, they assume that the degree of nominal rigidity between the sectors is the same. This assumption, however, is inconsistent with recent microevidence provided by the European Central Bank's Inflation Persistence Network (IPN), which reveals that producer prices adjust more frequently than consumer prices[2]. Nakamura and Steinsson's (2007a) findings indicate the same conclusion for the U.S. economy. In fact, this evidence is consistent with what a model of input-output linkages would predict. As Blanchard (1982) notes, "prices early in the chain of production move more and adjust faster, prices further in the chain move less and adjust more slowly".

This paper aims to answer the question of which inflation index the central banks should target by studying the question in a model that accounts for the asymmetries between the CPI sector and the PPI sector. To be specific, I use Huang and Liu's model to examine the monetary policy implications of alternative assumptions regarding the sectoral differences and explore how to assign weights to different sectors in an optimal inflation index for a central bank to target.

Two asymmetries will be the primary focus of the analysis: differences in the degree of nominal rigidity and in the degree of competition. I first examine the implications of differences in *the degree of nominal rigidity* for the optimal monetary policy design. I present a more realistic numerical example and calibrate the model with the empirically relevant frequencies of price adjustment for each sector for the U.S. economy. Second, I deal with the question of how differences in *the degree of competition* affect the optimal weights that the sector receives in an optimal inflation index. In a recent paper Lombardo (2006) argues that when constructing a price index for a central bank to target, a failure to take into account the possible differences in the degree of competition between the sectors can significantly affect policy evaluations. Unlike the degree of nominal rigidity, however, the de-

[2] See Dhyne, Alvarez, Bihan, Veronese, Dias, Hoffmann, Jonker, Lunnemann, Rumler and Vilmunen (2005) for a summary of IPN's findings on consumer prices and Vermeulen, Dias, Dossche, Gautier, Hernando, Sabbatini and Stahl (2007) for a summary of IPN's findings on producer prices.

gree of competition between different sectors is an issue surrounded by great uncertainty. First I will gauge the implications of the degree of competition uncertainty by evaluating the extent to which policy conclusions are sensitive to alternative assumptions regarding the degree of competition. I will then investigate the design of optimal monetary policy when the central bank faces uncertainty regarding the degree of competition in different sectors.

The conclusions of the paper are briefly summarised as follows. I find that once the empirically relevant frequencies of price adjustment for each sector are used to calibrate the model, the PPI inflation indeed receives a positive target weight. However, the weight is much less than in the case where the degree of nominal rigidity between sectors is assumed to be the same. The target weight of PPI inflation is around 18%, a little less than half of what it is under a symmetric degree of nominal rigidity[3].

The results also suggest that formulating and implementing a rule based on a belief that the degree of nominal rigidity is the same between the sectors results in poor outcomes if the PPI sector actually adjusts more frequently than the CPI sector. In contrast, if the central bank designs and implements monetary policy rule based on the assumption that the degree of nominal rigidity is relatively low in the PPI sector, this rule also performs reasonably well if the degree of nominal rigidity turns out to be the same. This result further strengthens the case for a rule that puts large weight on CPI inflation.

I show that, holding other things constant, an increase in the degree of competition in the PPI sector increases the optimal weight of the PPI inflation. However, when there is uncertainty regarding the degree of competition between sectors, a central bank is concerned with protecting itself against errors should assume a lower degree of competition in the PPI sector compared to the CPI sector and set the target weight of the PPI inflation as 12%. In contrast, welfare losses would be large if the central bank assumes that the degree of competition is higher in the PPI sector than the CPI sector.

Finally, I find that the strict output targeting rules perform very well in this model and give a welfare level close to optimum. This result also is in contrast to the finding of Huang and Liu. However, as is well known, this type of rule is not operational in the sense of Mccallum(1999), i.e., the rule requires a measurement of the natural rate of output in the economy, which

[3]Note that in a case where the degree of nominal rigidity between the sectors is the same, the optimal weight is 38%, not 46%, as argued by Huang and Liu. The difference arises due to a technical error in Huang and Liu's calculations.

is difficult and controversial. In practice central banks may still prefer to choose inflation as their target.

Therefore, this paper suggests that the policy implications of a model with input output connections is in line with the practice of many inflation targeting central banks, that pay close attention to "CPI inflation".

The remainder of the paper is organized as follows: Section 3 outlines the model. Section 4 derives a welfare function for a central bank based on a representative household's utility function. Section 5 characterizes optimal monetary policy. Section 6 looks at the implications of alternative assumptions regarding the sectoral differences for optimal monetary policy design and compares the performance of alternative simple rules. Section 7 summarizes the conclusions.

2 The Model

The model is the same as that in Huang and Liu (2005). The approach of the model is to incorporate intermediate goods into an otherwise standard DSGE model with monopolistic competition and no capital accumulation. The production of consumption goods requires a composite of intermediate goods and labour as inputs, whereas the production of intermediate goods requires labour as the only input. The exposition here aims to outline the basic elements of the model. There are three types of agents in the economy: firms, consumers and the government. First, I describe the behaviour of the households and the government, which are standard. Then, I describe the behaviour of the firms. Huang and Liu (2005) provide a detailed discussion of the underlying assumptions of the model and the derivation of the structural equations; thus, the presentation here is kept brief.

2.1 Structure of the Economy

There is a continuum of identical and infinitely lived households. These households derive utility form consumption and leisure. They buy a continuum of differentiated consumption goods, which they value according to a Dixit-Stiglitz aggregator. The government conducts monetary policy and provides production subsidies to eliminate any distortions in the steady state. The production subsidies are financed by lump-sum taxes.

The production of consumption goods goes through two stages of processing, from intermediate goods to finished goods. In fact, the production side of the economy can be thought of as having two sectors: sector m, in which the intermediate goods are produced and sector f, in which the final consumption goods are produced. Within each sector or each stage of processing, there is a continuum of firms. In each sector, the firms have a monopoly power over a specific product, for which the demand has a constant price elasticity θ_k for $k \in \{f, m\}$. In sector f, firms operate a technology $Y_{ft}(j) = \left(\bar{Y}_{mt}\right)^{\phi} \left(A_{ft} N_{ft}(j)\right)^{1-\phi}$ that transforms a composite of intermediate goods $\left(\bar{Y}_{mt}\right)$, which is a Dixit-Stiglitz aggregate of differentiated intermediate goods, and labour $(N_{ft}(j))$ into output (Y_{ft}) subject to productivity shocks (A_{ft}). In sector m, firms produce intermediate goods which are required to produce the final consumption goods. Firms in this sector operate a technology $Y_{mt}(i) = A_{mt} N_{mt}(i)$ that transforms labour $(N_{mt}(i))$ into output $(Y_{mt}(i))$ subject to productivity shocks (A_{mt}). The productivity shocks each follows an $AR(1)$ process with variances of innovations of σ_f and σ_m. Within each sector, firms set prices according to the Calvo process. Therefore, the optimal price in each sector is an effective markup (adjusted for subsidy) over a weighted average of the marginal costs of the future periods, during which the price is expected to remain in effect. The mark-up, μ_k, can capture many possible market structures from standard monopoly $\left(\mu_k = \frac{\theta_k}{\theta_k - 1}\right)$ to perfect competition $(\mu_k = 1)$. The degree of competition increases in θ_k. The price index of the intermediate goods corresponds roughly to PPI, whereas the price index of the finished goods corresponds to CPI.

2.2 Log-linearized Economy

In this section, I will simply present the log-linearised macroeconomic framework. We define $\tilde{c}_t = c_t - c_t^*$ as the gap between actual output, c_t and the flexible-price equilibrium output level c_t^*. The Euler condition from the representative household's consumption is given by

$$\tilde{c}_t = E_t \tilde{c}_{t+1} - \sigma^{-1}(r_t - E_t \pi_{ft+1} - rr_t^*) \tag{1}$$

where σ denotes the relative risk aversion in consumption, π_{ft} is the inflation rate in the finished goods sector, r_t is the nominal interest rate and $rr_t^* = r_t^* - E_t \pi_{ft+1}^*$ denotes the real interest rate when prices are flexible. r_t^* and π_{ft}^* denote the nominal interest rate and the CPI inflation rate when prices are flexible, respectively.

In each sector, the dynamics of inflation in terms of real marginal cost is described by an equation analogous to the one associated with a standard one-sector model:

$$\pi_{ft} = \beta \pi_{ft+1} + \kappa_f \tilde{v}_{ft} \tag{2}$$

$$\pi_{mt} = \beta \pi_{mt+1} + \kappa_m \tilde{v}_{mt} \tag{3}$$

with

$$\kappa_k = \frac{(1-\alpha_k)(1-\alpha_k \beta)}{\alpha_k} \text{ for } k \in \{f, m\}$$

where β is the discount rate, ϕ is the cost share of intermediate input in final goods production, $(1-\alpha_f)$ and $(1-\alpha_m)$ are the Calvo reset probabilities in the finished good sector and the intermediate good sector, respectively. $\tilde{v}_{ft}$ and $\tilde{v}_{mt}$ are the real marginal costs in the finished good sector and in the intermediate goods sector, respectively, and are given by

$$\tilde{v}_{ft} = (1-\phi)\sigma \tilde{c}_t + \phi \tilde{q}_t \tag{4}$$

$$\tilde{v}_{mt} = \sigma \tilde{c}_t - \tilde{q}_t \tag{5}$$

where $\tilde{q}_t = q_t - q_t^*$ is the relative price gap. $q_t = p_{mt} - p_{ft}$ denotes the relative price of intermediate goods in units of consumption goods and q_t^* denotes the value of this relative price in flexible-price level equilibrium. Note that it is no longer possible to express the real marginal cost entirely as a function of the output gap, as in a one-sector economy. In this economy, in each sector, the real marginal cost depends on the output gap as well as the relative price gap. High aggregate demand increases the real marginal cost and that increases inflationary pressure in both sectors. A high relative price in the intermediate sector reduces the real marginal cost and therefore inflationary pressure in that sector, whereas a high relative price in the finished good sector increases inflationary pressure in that sector.

The relative price gap is given by

$$\tilde{q}_t = \tilde{q}_{t-1} + \pi_{mt} - \pi_{ft} - \Delta q_t^* \tag{6}$$

where Δq_t^* is given by

$$\Delta q_t^* = (1 - \phi)(\Delta a_{ft} - \Delta a_{mt}) \tag{7}$$

where $\Delta a_{kt} = a_{kt} - a_{kt-1}$ is the productivity growth rate in sector $k \in \{f, m\}$.

Finally, the productivity growth rate shocks each follow an $AR(1)$ process. In particular,

$$\Delta a_{kt} = \rho_k \Delta a_{kt-1} + \varepsilon_{kt} \ , \ k \in \{f, m\}$$

where ε_{kt} is an $idd(0, \sigma_k^2)$.

3 Welfare Function: Woodford's Approximation

Huang and Liu (2005) follow the procedure described in Woodford (2003) and derive a utility based objective function of a central bank, to provide a benchmark for evaluating the performance of alternative inflation targeting monetary policy rules. In a model that leads to equilibrium conditions (1)-(6), Huang and Liu show that the second order approximation to the welfare of the representative household is given by

$$W_t = E\sum_{t=0}^{\infty} \beta^t U_t = -\frac{U_c(C)C}{2} E\sum_{t=0}^{\infty} \beta^t L_t + t.i.p + O(\|a\|^3) \tag{8}$$

where C is the steady state consumption, $U_c(C)$ is the marginal utility of consumption, $t.i.p$ collects all the terms that are independent of policy and $O(\|a\|^3)$ summarises all terms of the third or higher orders. The normalised quadratic loss function L_t is given by

$$L_t = \frac{\kappa_f \sigma}{\theta_f} \tilde{c}_t^2 + \frac{\kappa_f \phi (1 - \phi)}{\theta_f} (\sigma \tilde{c}_t - \tilde{q}_t)^2 + \pi_{ft}^2 + \phi \frac{\kappa^{gap}}{\theta^{gap}} \pi_{mt}^2 \tag{9}$$

where

$$\theta^{gap} = \tfrac{\theta_f}{\theta_m}, \quad \kappa^{gap} = \tfrac{\kappa_f}{\kappa_m}, \quad \kappa_k = \tfrac{(1-\alpha_k)(1-\alpha_k\beta)}{\alpha_k} \text{ for } k \in \{f, m\}$$

where θ_k denotes the elasticity of substitution between the differentiated goods in sector $k \in \{f, m\}$.

This loss function is similar to that obtained in a standard one-sector model, in which the central bank only cares about fluctuations in the output gap and CPI inflation, but involves two additional terms: variances of PPI inflation and the marginal cost gap in the intermediate sector. In fact, when $\phi = 0$, the loss function reduces to the loss function in a standard one-sector model, as in Woodford(2003, p. 400).

When discussing the weight that should be assigned to PPI inflation, Huang and Liu emphasised the role of the share of intermediate goods. However, it is important to note that the weight assigned to the PPI sector in the loss function depends not only on the share of intermediate goods but also on the nominal rigidity gap, $\kappa^{gap} = \frac{\kappa_f}{\kappa_m}$,and the competition gap, $\theta^{gap} = \frac{\theta_f}{\theta_m}$. Thus, the share of intermediate goods, the nominal rigidity gap and the competition gap, taken together, determine how much the central bank should care about the variability of PPI inflation. Even if one considers the case in which the share of intermediate goods gives rise to its greatest concern about fluctuations in the PPI sector, i.e. $\phi = 1$, this does not necessarily mean that the central bank should assign significant weight to the variations in the PPI inflation. Consider, for example, the extreme case in which prices in the CPI sector are sticky, whereas prices in the PPI sector can adjust every period. In this case, for any degree of competition, the weight assigned to the variations in the PPI sector is zero.

What happens more generally? For any degree of competition, if prices in the PPI sector adjust more frequently relative to the prices in the CPI sector, then the variations in the PPI sector become less important, and the weight assigned to the PPI is smaller, compared to the case in which the sectors have the same degree of nominal rigidity. Similarly, for any given degree of nominal rigidity, if the PPI sector is more competitive relative to the CPI sector, then PPI inflation becomes more important and vice versa.

The bottom line, therefore, is that the share of intermediate goods as well as the nominal rigidity gap and the competition gap play crucial role in shaping the central bank's objective. Ignoring any of these factors would result in an objective function that would not be the appropriate objective of policy and may lead to the design of welfare maximizing inflation targeting rules that may not be appropriate for implementation.

4 Optimal Monetary Policy

In the model, as noted by (Huang and Liu (2005)),the Pareto optimal allocation cannot be achieved, so long as $0 < \phi < 1$. As the loss function (equation 9) makes explicit, an equilibrium allocation is Pareto optimal in this model only if the gaps and the inflation rates are zero in every period, that is $\tilde{c}_t = \tilde{q}_t = \pi_{ft} = \pi_{mt} = 0$ for all t. However, it is impossible to satisfy all these stabilization objectives at the same time and therefore Pareto optimal allocation is not attainable. This is most easily seen by considering the case in which $\tilde{c}_t = \tilde{q}_t = 0$. When $\tilde{c}_t = \tilde{q}_t = 0$,it follows from equations (2),(3),(4) and (5) that $\pi_{ft} = \pi_{mt} = 0$. However, equations (6) and (7) imply that $\pi_{ft} - \pi_{mt} = (1-\phi)(\Delta a_{ft} - \Delta a_{mt})$,which is inconsistent with the requirement that $\pi_{ft} = \pi_{mt} = 0$ unless the shocks are identical $(\Delta a_{ft} - \Delta a_{mt})$.

Given that the first best allocation cannot be achieved, I employ Lagrangian methods to determine the optimal monetary policy. In particular, I compute the optimal policy that can be obtained by maximizing the welfare level defined in (8) subject to the equilibrium conditions (1)- (6). I obtain the first order conditions of this problem by differentiating the Lagrangian with respect to each of the endogenous variables and setting these conditions to zero. The first order conditions are given by

$$(\frac{\theta_f}{\kappa_f})\pi_{ft} + \lambda_{ft} - \lambda_{ft-1} - \lambda_{qt} = 0 \tag{10}$$

$$(\frac{\theta_m}{\kappa_m})\pi_{mt} + \lambda_{mt} - \lambda_{mt-1} + \lambda_{qt} = 0 \tag{11}$$

$$\sigma\tilde{c}_t + \phi(1-\phi)(\sigma\tilde{c}_t - \tilde{q}_t)\sigma - \lambda_{ft}(1-\phi)\kappa_f\sigma - \lambda_{mt}\kappa_m\sigma = 0 \tag{12}$$

$$-\phi(1-\phi)(\sigma\tilde{c}_t - \tilde{q}_t) - \lambda_{ft}\kappa_f\phi + \lambda_{mt}\kappa_m - \lambda_{qt} + \lambda_{qt+1} = 0 \tag{13}$$

where $\lambda_{ft}, \lambda_{mt}$ and λ_{qt} denote the Lagrangian multipliers associated with the constraints. These first order conditions hold for each date $t \geqslant 1$. They also hold at time zero, if one substitutes the values

$$\lambda_{q,-1} = \lambda_{f,-1} = \lambda_{m,-1} = 0 \tag{14}$$

These conditions at time zero simply reflect the fact that in period zero there is no previous policy commitment that the central bank needs to take into account. Given that each of these first-order conditions hold at each period

t, they should also hold under commitment[4].

I then use central bank's first order conditions along with the equilibrium conditions for the model to solve and calculate the level of welfare under optimal monetary policy.

While this is a useful reference to evaluate the performance of alternative simple rules, as discussed in Huang and Liu (2005), it is difficult to implement, as it requires the knowledge of leads and lags of the inflation rates and the output gap.

5 Monetary Policy Rules

I consider the performance of simple rules with coefficients chosen to maximize welfare function in equation (8). I examine the performance of alternative inflation targeting rules under which the interest rate reacts to the lagged interest rate, the CPI inflation as well as PPI inflation. In particular, I consider an inflation targeting rule with the following form:

$$r_t = a_r r_{t-1} + a_{\pi_f} \pi_{ft} + a_{\pi_m} \pi_{mt} \tag{15}$$

I also examine the performance of simple rules under which the policy instrument r_t targets the output gap. In this case, the interest rate rule is given by

$$r_t = a_r r_{t-1} + a_y \tilde{c}_t \tag{16}$$

In a two-sector model, Woodford(2003, p. 441-442) shows that strict targeting of the output gap gives welfare outcome nearly identical to that under an optimal policy. Therefore, it would be interesting to see whether Woodford's conclusion holds in a model that features input-output connections between the CPI sector and the PPI sector.

[4]However, as is well-known(e.g. Woodford (2003), p. 473, Wolman (2001) p. 41), this policy is not time-consistent. This is true because if the central bank were allowed to reoptimize in period $t > 0$ to determine the optimal policy commitment from that period onward, the policy chosen would be different from the policy selected in period $t = 0$.

6 Choice of Parameters and Computation

I begin with a calibration of the parameters indicating the degrees of nominal rigidity in the PPI sector, α_m and the CPI sectors α_f. Huang and Liu (2005) assume that the degree of nominal rigidity between the sectors is the same. In particular, they set $\alpha_m = \alpha_f = 0.75$. However, this assumption is inconsistent with recent microeconomic evidence provided by Nakamura and Steinsson (2007a).

Nakamura and Steinsson (2007a) present evidence on the proportion of prices that change in a month for consumer prices across categories and for the intermediate goods across categories of the US economy[5]. The findings reported there suggest that in the U.S. economy, intermediate goods prices adjust more frequently than consumer prices. Nakamura and Steinsson (2007a) note that there is a large amount of heterogeneity across categories both in consumer prices and in the intermediate goods prices and emphasize the median frequency of price changes when summarizing the empirical distribution of price change frequencies. In particular, they find that the median frequency of price changes for consumer prices is 8.7% per month, whereas the corresponding figure for intermediate goods prices is 13.3%[6]. Following Bils and Klenow (2004), I interpret this statistic as a Calvo reset probability. I convert these monthly figures to quarterly figures and use them to calibrate the model for the U.S. economy. I assume that $\alpha_f = 0.73$ and $\alpha_m = 0.60$.

The other two important parameters to calibrate are θ_m and θ_f,which measure the elasticity of substitution between differentiated goods at the two stage of processing. Given the scarcity of disaggregated evidence on these two parameters, following Huang and Liu, I proceed by calibrating $\theta_m = \theta_f = 10$, which corresponds to a steady state markup of 11%. I will then assess the policy and welfare implications of alternative combinations of these parameters.

The rest of the parameter values are taken from Huang and Liu (2005). In

[5] For the US, there is no "entire PPI index". The PPI is represented in a three stage-of-process format (finished goods, intermediate goods and crude materials). These are three separate indexes and are not combined into an aggregate index. See http://www.bls.gov for a full discussion.

[6] Note that these numbers exclude sales. This is the approach taken by Golosov and Lucas (2007) and Nakamura and Steinsson (2007b). As Golosov and Lucas (2007) notes when discussing whether sales should be excluded, "To obtain a good match between theory and data, then, sales must either be removed from the data or added to the model...we took the first course"

particular, I assume that the cost-share of intermediate goods in final goods production to $\phi = 0.6$. I use a discount factor β of 0.99 which corresponds to the annual real interest rate in the steady state of 4%. I assume that $\omega = 0$, which implies that the representative household's utility is linear in labour hours. Finally, I set $\rho_k = 0.95$ and the standard deviations of innovations to productivity shocks σ_k to 0.02.

6.1 Computation

I use Dynare to solve the model (see Juillard (1996)). To compute the optimal weights in the optimal inflation index, I numerically minimize the welfare loss with respect to the parameters in the monetary policy rule, $a-$coefficients, subject to the equilibrium conditions ((1)- (6)). To do so, I use the optimization routine "fminsearch" in Matlab 7.

Note that there is a slight error in Huang and Liu's Matlab code. In their Matlab code, when they define the inverses of κ_f and κ_m,they miss a pair of parentheses. In effect, the inverses of κ_f and κ_m are defined as $d_f^{HL} = \frac{1}{\kappa_f} = \frac{\alpha_f\left(1-\alpha_f\right)}{\left(1-\beta\alpha_f\right)}$, $d_m^{HL} = \frac{1}{\kappa_m} = \frac{\alpha_m(1-\beta\alpha_m)}{(1-\beta\alpha_m)}$. The correct definitions are $d_f = \frac{1}{\kappa_f} = \frac{\alpha_f}{\left(1-\beta\alpha_f\right)\left(1-\alpha_f\right)}$, $d_f = \frac{1}{\kappa_m} = \frac{\alpha_m}{(1-\beta\alpha_m)(1-\alpha_m)}$. As discussed in section 3, the price dispersion in each sector in sector $k \in \{f, m\}$ depends on the d_k. Huang and Liu (2005) set $\alpha_f = \alpha_m = 0.75$. When $\alpha_f = \alpha_m = 0.75$, $d_k^{HL} < d_k$. Therefore, the degree of price dispersion in each sector is underestimated in Huang and Liu (2005).

7 Results

The aim of this section is to investigate the effects of the asymmetries between the CPI sector and the PPI sector in optimal monetary policy design. As discussed above, I will first consider the performance of inflation-targeting rules and will then consider the case in which the central bank targets the output gap. Throughout the paper, welfare levels (W) are expressed in terms of the equivalent percentage decline in steady state consumption, which can be obtained by dividing W by U_cC (and multiplied by 100).

7.1 Inflation Targeting Rules

In this subsection, I examine the performance of the inflation-targeting rules with coefficients chosen to maximise welfare in the model. The main goal of this section is to investigate the relationship between the optimal policy parameters a_{π_f} and $a_{\pi_m,}$ and the difference in the degree of nominal rigidity between the sectors, as well as the difference in the degree of competition. However, before presenting my main results by using the chosen parameter values for α_m, α_f, θ_m and θ_f, it is useful to discuss possible effects of structural asymmetry on optimal monetary policy design.

7.1.1 The Implications of Different Degree of Nominal Rigidity

I begin by looking at the implications of different degrees of nominal rigidity. I let the value of the of Calvo-PPI parameter, α_m, vary from 0.75 to 0. For the sake of comparison, I set the value of the Calvo CPI-sector parameter, α_f ,to be 0.75, which is the value of α_f assumed by Huang and Liu, with the other parameters held at baseline values. For each case, I optimise the coefficients of the hybrid rule to maximise welfare in the model, then use the optimised coefficients, construct an optimal inflation index and calculate the weight that the PPI inflation receives in such an index. The optimal weight that the PPI sector receives is given by $a_{\pi_m}/\left(a_{\pi_f}+a_{\pi_m}\right)$.

The welfare levels under the hybrid rule and the optimal policy are reported in Figure 1. Figure 2 reports the optimal weight, which the PPI sector receives in the optimal index. As Figure 1 shows, the hybrid rule performs very well and gives a welfare outcome close to the optimum. However, the net benefit of switching to the hybrid rule depends on the degree of nominal rigidity in the PPI sector. For example, when the degree of nominal rigidity between the sectors is the same, then the optimal CPI rule incurs a welfare loss of 4%, which is about 1.6 times the loss under the optimal policy[7]. However, as the figure shows, the net gain of using the hybrid rule falls dramatically as the PPI sector becomes more flexible. The question

[7] The scale of welfare losses is in line with that of in Canzoneri, Cumby and Diba (2006). However, the scale is different from that of in Huang and Liu. For example, when the degree of nominal rigidity between the sectors is the same, the findings reported in Huang and Liu suggest that the CPI rule incurs a welfare loss of 0.25%. The difference in scale arises due to the fact that, for the reasons discussed earlier, the price dispersion in each sector is underestimated in Huang and Liu.

then arises: how does the optimal weight of the PPI sector changes as the relative frequency between the sectors change? Five points should be made:

First, as evident from Figure 2, the optimal weight of the PPI sector is highly sensitive to the Calvo parameter in that sector and decreases as the PPI sector adjusts more frequently relative to the consumer prices. This result is closely related to the findings of Benigno (2004), Mankiw and Reis (2003) and Woodford (2003).

Second, if the degree of nominal rigidity between the sectors is the same, which corresponds to the case studied by Huang and Liu, the target weight that the PPI sector receives is as high as 38%. Note that this number is lower than the value reported by Huang and Liu. The corresponding value in Huang and Liu is 46%. The difference from Huang and Liu seems to arise from the error described above.

Third, small differences in the relative frequency can lead to significant decreases in the optimal PPI weight. For example, if the relative frequency between the sectors is only 10%, then the optimal weight should be reduced by 15%, passing from 0.38 to 0.33.

Finally, if the PPI sector has fully flexible prices, then the optimal weight that the PPI sector receives in the optimal index is zero, which is in line with the findings of Aoki (2001).

The main reason for these results is that, as discussed earlier, the central bank should also care about variations in PPI inflation. The reason why PPI inflation enters the loss function is that the production of intermediate goods requires labour as an input. The demand for labour input ($\tilde{n}_{mt}$) in this sector is given by

$$\tilde{n}_{mt} = -\left(1-\phi\right)\tilde{q}_t + \left(1+\left(1-\phi\right)\sigma\right)\tilde{c}_t + \int_0^1 \left(\frac{P_{ft}(i)}{P_t}\right)^{-\theta} di + \int_0^1 \left(\frac{P_{mt}(i)}{P_t}\right)^{-\theta} di \tag{17}$$

The demand for labour input in the PPI sector depends on the price dispersion $\left(\int_0^1 \left(\frac{P_{mt}(i)}{P_t}\right)^{-\theta} di\right)$ caused by sticky prices in that sector. It is through this channel that PPI inflation turns out to be relevant for welfare. Indeed, as discussed above, the weight assigned to PPI inflation in the loss function decreases as the degree of nominal rigidity in that sector decreases. As a result, variations in PPI inflation becomes less important as the contract duration decreases and, therefore, PPI inflation receives less weight in the optimal inflation index as the contract duration decreases. In addition to this, the inflation process in the CPI sector is influenced by the price level in the PPI sector. This can be seen easily by rewriting the real marginal cost in the CPI sector in nominal terms. Using equations (4) and (5), one can clearly show that marginal cost in the CPI sector is related to the price level in the PPI sector (p_{mt}) by

$$v_{ft} = \sigma \tilde{c}_t + \phi p_{mt} + (1 - \phi) p_{ft} - \phi q_t^* \tag{18}$$

Thus, there is a spillover effect from the PPI sector to the CPI sector via the marginal cost. As a result, ignoring fluctuations in PPI inflation would be even more disruptive. A policy rule that stabilises fluctuations in PPI inflation would also minimise the disruptive effect of the PPI sector on the CPI sector.

It is important to note that the results are also related to the finding obtained in a model with sticky prices and sticky wages, such as Erceg, Henderson and Levin (2000) in which it is argued that optimal monetary policy can be closely approximated by targeting nominal wages. As noted by Huang and Liu, the main difference between this model and that of Erceg et al. (2000) is that in Erceg et al. (2000) the primary input is labour rather than intermediate goods. However, this difference has important implications on monetary policy design. This is because the nominal rigidity of labour contracts is of a different nature from the nominal rigidity of intermediate goods. If we think of labour as the primary input, the degree of nominal rigidity would probably be much higher than that for intermediate goods. Therefore, as the findings above suggest, if I were to assume that the primary input is labour, then the optimal weight of this sector would have been large.

7.1.2 An Application to U.S. Data

I have thus far established the intuitions on the mechanism through which sectoral asymmetries can affect the policymaker's objective function and the optimal weights that the sectors receive in the optimal inflation index. The findings in the previous section explicitly show that differences in the nominal rigidity between the PPI sector and the CPI sector have significant implications on the design of an optimal monetary policy. The question is then: how much weight should the central banks assign to the PPI and the CPI in reality?

Table 1 provides an answer by applying the model to frequencies of price adjustment for the U.S. economy. Reported here is the target weight of the PPI inflation in the optimal inflation index and the relative degree of stickiness between the sectors.

My conclusion is evident: once the empirically relevant contract lengths for each sector are used to calibrate the model, the PPI inflation indeed receives a positive target weight, but the weight is much less than in the case where it is assumed that both sectors have the same degree of nominal rigidity In particular, the target weight on the PPI sector is around 18%, roughly half of what it is under a symmetric degree of nominal rigidity.[8] [9]

7.1.3 Degree of Nominal Rigidity Uncertainty

How important is the finding in the previous section? In order to understand the importance of this finding I consider the case in which the central bank formulates its policy by assuming, incorrectly, that sectors are identical in terms of degree of nominal rigidity, when in fact they are not. As empirical evidence surveyed in section 1 reveals, the PPI sector adjusts more frequently than the CPI sector. I then compute the welfare loss under such a policy rule in the true economy.

Table 2 reports the welfare losses under the policymaker's misperceptions about the degree of nominal rigidity between the sectors. The table indicates that if the PPI sector is more flexible than the CPI sector in the true economy, then formulating monetary policy based on the incorrect assumption that the sectors are the same in terms of their contract length would lead to substantial welfare losses.

How robust is this rule which gives substantial weight to the CPI inflation? To assess the robustness of this rule, I consider the case in which the policymaker optimises the parameters of the policy rule based on the assumptions that in the PPI sector the prices adjust more frequently than the prices in the CPI sector. However, in the true economy it turns out that the

[8] I have also used the mean frequencies of adjustment to calibrate the model. Using the mean, instead of the median, does not change the results significantly. In the case of the mean, $\alpha_f = 0.37$ and $\alpha_m = 0.2$ and the optimal PPI weight is 17%.

[9] I have also calibrated the model for the Euro-Area by using the mean frequencies of adjustment. Unfortunately, the median frequencies of adjustment are not available for the Euro-Area. Calibrating the model for the Euro-Area does not change the results significantly. In the case of the Euro-Area, $\alpha_f = 0.55$, $\alpha_m = 0.34$ and the optimal PPI weight is around 15%.

degree of nominal rigidity between the sectors is the same. I again compute the welfare loss under such a policy rule in the true economy.

As Table 2 shows, employing a rule that is optimised under the assumption that the prices in the PPI sector adjust more frequently within a model that assumes the same degree of nominal rigidity between the sectors results in a welfare loss. This level of loss is much less than the case in which the monetary policy is formulated by assuming the same degree of nominal rigidity. More specifically, the increase in the value of loss is roughly half of that under the previous case.

Table 3 shows the reasons for this result. Reported in the table are the standard deviations of the output gap, CPI inflation and PPI inflation under central bank's misperceptions about nominal rigidities. Consider first the case in which the central bank formulates its policy by assuming that prices in the PPI sector adjusts more frequently than prices in the CPI sector, whereas in the true economy the degree of nominal rigidity between the sectors is the same. As noted above, in this case, the target weight on PPI inflation is around 18%, whereas the corresponding number in the true economy is around 38%. Not surprisingly, increased target weight on CPI inflation leads to lower CPI inflation variability but that comes at the cost of greater PPI inflation and output gap variability. On the other hand, if the central bank, when formulating its policy, overestimates the degree of nominal rigidity in the PPI sector, then the more aggressive response to PPI inflation leads to lower PPI inflation variability; however, that then leads to greater CPI inflation and output gap variability. The increase in CPI inflation volatility is more costly in the latter case, since the rise in CPI inflation volatility has more weight in the loss function. Thus, overestimating the degree nominal rigidity in the PPI sector leads to a larger deterioration in social welfare.

7.1.4 Degree of Competition Uncertainty

Evidence concerning the degree of competition between the PPI sector and the CPI sector is scarce. It should be noted that there are some studies that argue that the frequency of price adjustment increases with market concentration (e.g. Carlton (1986) and Powers and Powers (2001)). However, a recent study, Bils and Klenow (2004) finds that market power, as measured by market concentration, is not an accurate predictor of the frequency of price changes. Given this uncertainty, when examining the implications of the relative degree of nominal rigidity on optimal monetary policy, I follow

Huang and Liu to assume that the degree of competition between the sectors is the same. Specifically, I set $\theta_m = \theta_f = 10$. However, before drawing any firm policy conclusions, it is essential to check the sensitivity of policy conclusions to alternative assumptions regarding the degree of competition between the sectors. As pointed out by Lombardo (2006), when constructing an inflation index for a central bank to target in a two sector model, the differences in the degree of competition between the sectors can affect policy conclusions. I now consider the situations in which the degree of competition between the sectors differs.

Figure 3 performs the same exercise as in Table 1 but with alternative assumptions regarding the relative degree of competition between the sectors. As expected, allowing for different degrees of competition between the sectors effects the optimal weights. The optimal weight on PPI decreases as the competition gap, $\theta^{gap} = \frac{\theta_f}{\theta_m}$, increases and vice versa. However, it should be noted that the effect is small expect in cases where there is a significant difference in the degree of competition between sectors. The reason for these results is that price dispersions caused by sticky prices in sector $k \in \{f, m\}$ increases θ_k due to the assumed Dixit-Stiglitz preferences. The higher the θ_k (i.e. the goods are more substitutable); as the price dispersion in the PPI sector increases, the more disruptive it becomes. Therefore, the target weight of the PPI sector increases with increases in θ_k.

Given this finding, a question arises: how should a central bank concerned with protecting against error act when there is uncertainty regarding the degree of competition? To answer this, I investigate the consequences of employing an incorrect combination of values for the parameters which characterise the degrees of competition in the sectors by using the notion of fault tolerance introduced by Levin and Williams (2003). More specifically, I consider variations in θ_m^P, from 2 to 20, which denotes the central bank's perceived value of θ_m,while θ_f and the other parameters are held at the baseline values. For a given value of θ_m^P, I let the central bank find the optimal coefficients in the policy rule based on θ_m^P, which may differ from θ_m, the parameter that characterises the actual degree of competition in the PPI sector. I then compute the welfare loss under such a policy rule with θ_m[10].

Figure 4 plots the welfare losses under misperceived degree of competition

[10]The exercise is similar to the previous study by Walsh (2005) in assessing the consequences of formulating monetary policy under possible misperceptions of the model parameters.

(θ_m^p) relative to that under correct degree of competition (θ_m). The figure shows that the central bank can avoid most of the losses due to competition uncertainty by assuming that the degree of competition in the PPI sector is lower than the CPI sector. In other words, underestimating θ_m^P appears to lead to a more robust policy. Here, a min-max strategy would set $\theta_m^P = 6$, which implies that the target weight of the PPI sector is 12%. When $\theta_m^P = 6$, the average loss is never more than 20% worse than the loss under the correct degree of competition. Note that when $\theta_m^P = 2$, which implies that the target weight of the PPI is 4%, the average loss is no more than 33% worse than the loss under the correct degree of competition; whereas, when $\theta_m^P = 20$, the target weight of the PPI is 30% and the average loss can be more than 270% than the loss under the correct degree of competition.

Thus, a policy rule that does not completely ignore PPI inflation but gives substantial weight to CPI inflation exhibits much greater fault tolerances. In contrast, a policy that gives substantial weight to both CPI inflation and PPI inflation can lead to substantial welfare losses.

7.2 Output Gap Targeting

I now consider the performance of the output gap targeting rule. Figure 5a plots the welfare level under the optimal policy and the output gap targeting when α_m varies from 0 to 1, while fixing the other parameters at the baseline values. Figure 5b performs the same exercise, as in Figure 5a, but it considers variations in θ_m.

As evident from the figures, a simple rule under which the central bank responds to the output gap yields a welfare outcome nearly identical to the optimal policy regardless of the relative frequency of price adjustment and of competition. The reason for this result can be easily seen by simply summing the inflation equations for sectors f and m, which gives

$$\pi_t^a = \beta \pi_{t+1}^a + \sigma \tilde{c}_t \tag{19}$$

where

$$\pi_t^a = \frac{1}{\kappa_f} \pi_{ft} + \phi \frac{1}{\kappa_m} \pi_{mt}$$

It follows from this equation that a policy that targets the output gap can also eliminate fluctuations in π_t^a, which suggests that output gap stabilization is equivalent to stabilization of inflation in this model.

Given this finding, it can also be concluded that any simple rule (e.g. optimal Taylor rule) under which the coefficients are optimally chosen and includes the output gap as a targeting variable would yield a welfare outcome that is close to optimum. This result contradicts with the finding of Huang and Liu (2005), who argued that the incorporation of the output gap as an additional targeting variable does not affect welfare results. The difference from Huang and Liu seems to arise from the error in Huang and Liu (2005).

Although strictly targeting of the output gap gives outcome close to optimum, as has been pointed out by various authors (see for example Erceg and Levin (2005), Levin, Onatski, Williams and Williams (2005), Woodford (2003)), this type of rule is not operational in the sense of McCallum (1999). That is, this type of rule is demanding concerning the knowledge of the economy. In particular, it requires measurement of the natural rate of output in the economy. However, measurement of the natural rate of output and,therefore, of the output gap is difficult and controversial. Therefore, in practice central banks may still prefer to choose inflation as their target.

8 Summary and Conclusions

I have shown that in a model which features input-output connections between sectors such that a distinction between CPI and PPI arises from the model, a welfare maximizing central bank should use an optimal inflation index that gives substantial weight to CPI inflation. For those familiar with the conclusion of Huang and Liu (2005), this result should be surprising. They argue that the "optimal inflation index" should place substantial weight on both CPI inflation and PPI inflation.

The main difference is in our assumptions regarding the degree of nominal rigidity between sectors. Huang and Liu, in arriving at their conclusion, incorrectly assume that the degree of nominal rigidity between the sectors is the same, when in fact it is not. Microevidence suggests that producer prices adjust more frequently than consumer prices. The degree of nominal rigidity between sectors plays an important role in determining the weights assigned to sectors. The weight on PPI inflation is small if prices in this sector are more flexible, as the prices can adjust more frequently and the disruptive effect of PPI inflation in the economy is small. I apply the model to the U.S. economy and find that the optimal PPI weight is approximately 18%.

The degree of competition between sectors can also affect the optimal weights assigned to sectors. Holding other factors constant, increased competition in the PPI sector increases the target weight of the PPI sector. However, the degree of competition between different sectors is an issue of great uncertainty. I examine how monetary policy should be formulated when the central bank faces uncertainty regarding the degree of competition uncertainty. The results suggest that a central bank concerned with protecting itself against errors should assume that a lower degree of competition in the PPI sector compared to the CPI sector. In this case, the optimal PPI weight is around 12%.

These findings suggest that central banks should use an optimal inflation index that puts large weight on CPI inflation. In fact, a variety of comparisons indicate that if central banks use the inflation index that assigns substantial weight to stabilizing both CPI and PPI, then the welfare loss would be large.

Finally, it may be useful to note that the strict output targeting rules perform very well in this model and give a welfare level close to the optimum. However, it is well known that this type of rule is not easy to implement, as this rule requires measurements of the natural rate of output in the economy, which is difficult and controversial. Therefore, a rule targeting inflation that mainly focuses on CPI inflation represents a sensible approach to policy.

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	$\frac{1-\alpha_m}{1-\alpha_f}$	The optimal weight of PPI inflation
The U.S. Economy	1.52	0.18

Table 1: The optimal weight of PPI inflation with empirically relevant frequencies

Actual rigidities	Perceived rigidities	
	$\alpha_f = 0.73, \alpha_m = 0.60$	$\alpha_f = 0.73, \alpha_m = 0.73$
$\alpha_f = 0.73, \alpha_m = 0.60$	1.00	1.28
$\alpha_f = 0.73, \alpha_m = 0.73$	1.18	1.00

Table 2: Welfare Losses when the central bank misperceives the relative degree of nominal rigidity between sectors

Actual rigidities	Perceived rigidities					
	$\alpha_f = 0.73, \alpha_m = 0.60$			$\alpha_f = 0.73, \alpha_m = 0.73$		
	$\tilde{c}_t$	π_{ft}	π_{mt}	$\tilde{c}_t$	π_{ft}	π_{mt}
$\alpha_f = 0.73, \alpha_m = 0.60$	0.03	0.65	2.95	0.65	1.36	2.21
$\alpha_f = 0.73, \alpha_m = 0.73$	0.82	0.65	2.94	0.05	1.36	2.21

Table 3: Standard deviations(%) when the central bank misperceives the relative degree of nominal rigidity between sectors

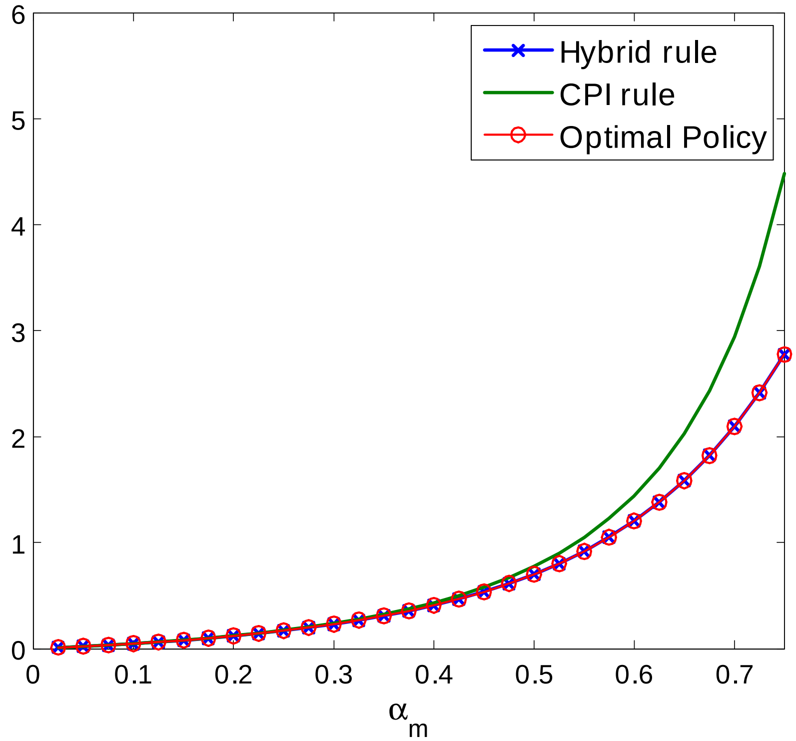

Figure 1: Welfare losses under alternative inflation targeting regimes for different degrees of nominal rigidity in producer prices ($\alpha_f = 0.75$): percent of steady state consumption.

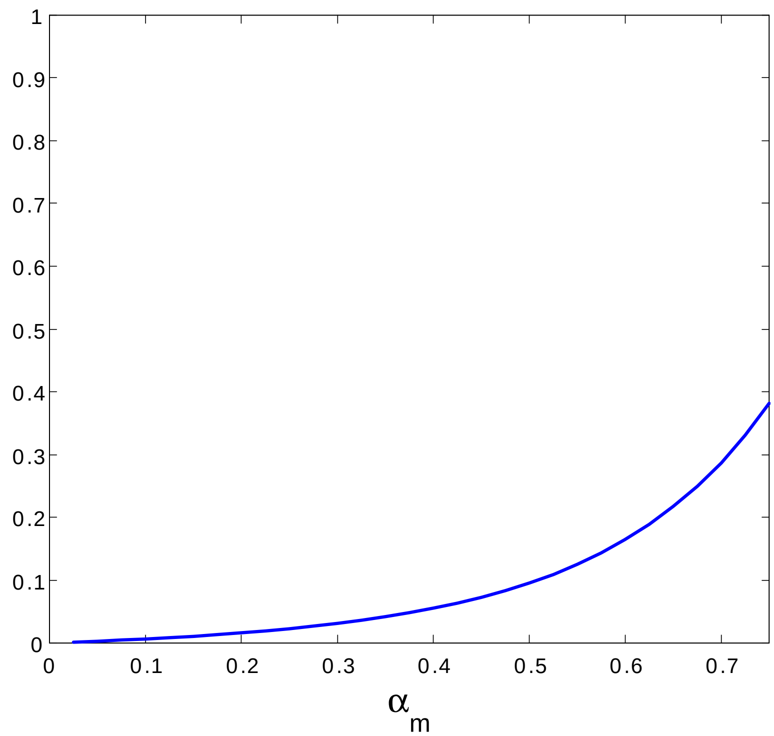

Figure 2: The weight on PPI inflation in the optimal inflation index for different degrees of nominal rigidity in producer prices $(\alpha_f = 0.75)$.

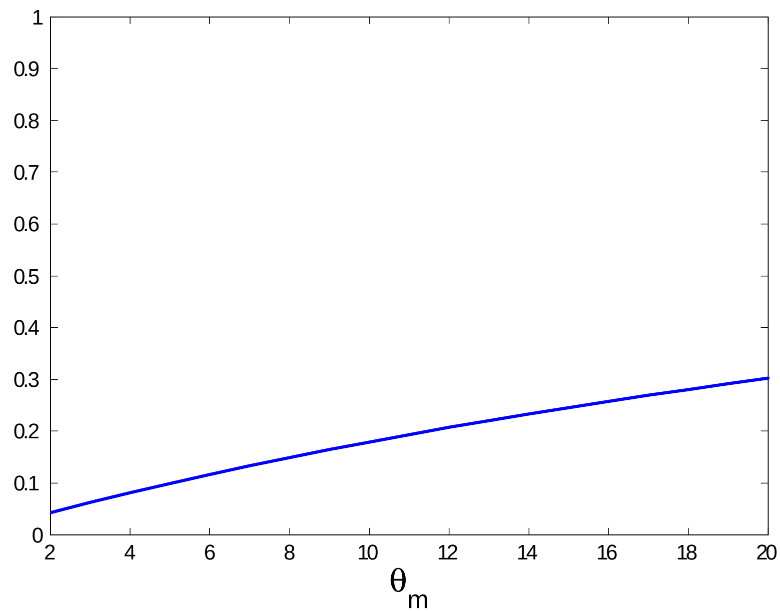

Figure 3: The weight on PPI inflation in the optimal inflation index for different degrees of competition in producer prices ($\theta_f = 10$).

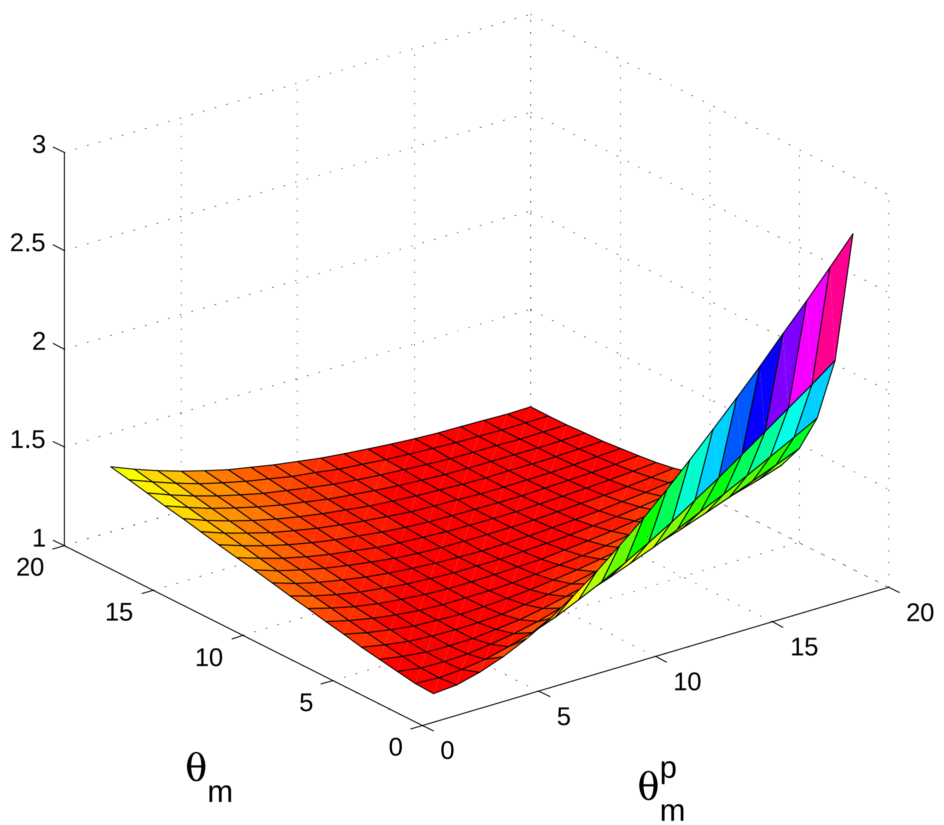

Figure 4: The welfare losses under misperceived degree of competition (θ_m^p) relative to that under correct degree of competition (θ_m)

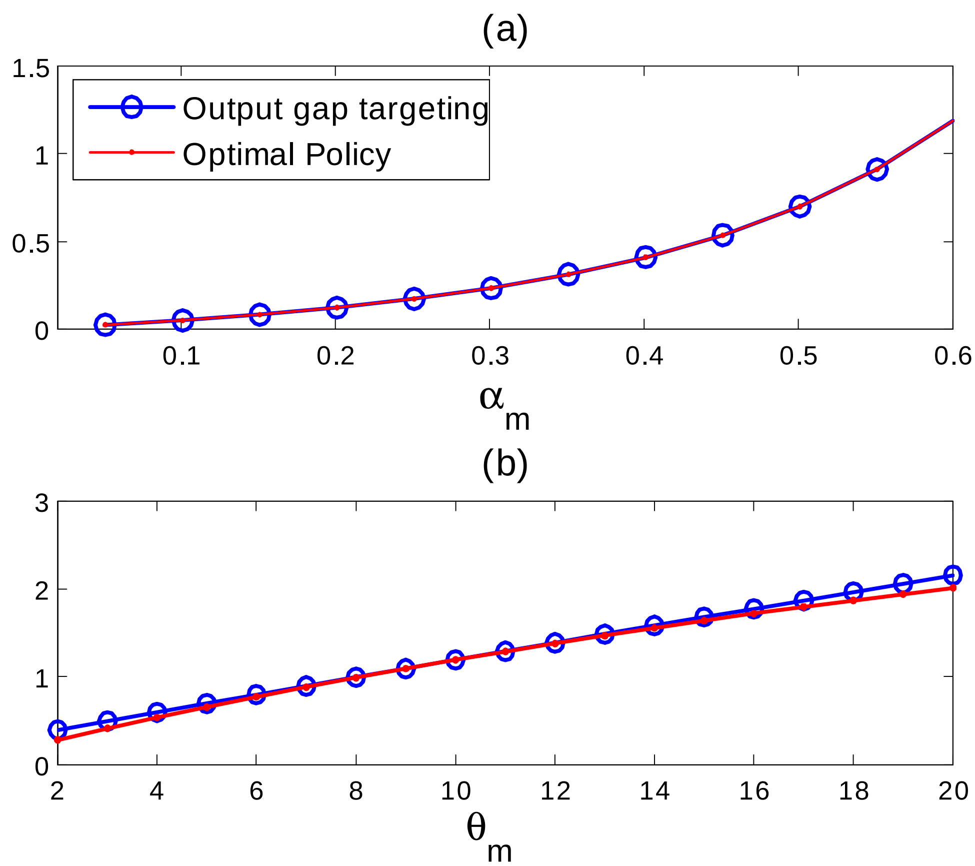

Figure 5: (a). welfare losses under output gap targeting for different degrees of nominal rigidity in producer prices: percent of steady state consumption. (b). welfare losses under output gap targeting for different degrees of competition in producer prices: percent of steady state consumption.

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